

RESEARCH ARTICLE

Aerosol and spatter mitigation in dentistry: Analysis of the effectiveness of 13 setups

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Abstract

Objectives: The current study aims to investigate the aerosol and spatter mitigation quality of 13 dry-field isolation methods in a simulated setup that replicates real-life work scenarios encountered in dental practices.

Methods: A crown preparation on a manikin was performed on tooth number 30 and repeated five times for each setup to simulate a patient under care. Aerosol, environmental, and operator face shield spatter, and sound intensity was measured. Generalized linear mixed models were used, and posthoc pairwise comparisons were performed to compare least-squares means when appropriate using a Tukey adjustment.

Results: All tested setups showed some environmental spatter formation; however, these were able to control most (and in some cases all) spatter on the operator face shield. All methods resulted in excellent aerosol mitigation when a second line of high-volume evacuation (HVE) was added to the device setup. However, in most setups, total sound levels exceeded 85 dB, posing a concern for prolonged noise exposure.

Conclusions: The Prototype device and four other tested setups with secondary HVE addition completely eliminated aerosol creation as tested. Spatter of the Face Shield was best eliminated using the Prototype device.

Clinical Significance: Within the limitations of this study, it can be concluded that the dental community has at its disposal equipment that can effectively mitigate aerosol and spatter.

KEYWORDS

aerosol mitigation, COVID-19, environmental spatter, face shield spatter, SARS-CoV-2, total sound level (TSL)

1 | INTRODUCTION

The effect of SARS-CoV-2 in dentistry has been particularly concerning.^{1,2} The SARS-CoV-2 virus appears to be unique compared to other viruses. The virus apparently can spread in the absence of

clinical symptomatology, or more likely, the symptoms may be so subtle that it is often unrecognized by those who are affected or their caretakers.^{3,4}

It was submitted that one of the primary mechanisms of SARS-CoV-2 virus transmission is via aerosols^{5,6} known to be generated

throughout dental procedures.⁷⁻¹² It has been shown that the SARS-CoV-2 virus can be detected in the saliva of affected patients.^{13,14} The virus binds to the human angiotensin-converting enzyme-2 receptor,^{14,15} that is highly concentrated in human salivary glands and ducts, leading to the postulate that the SARS-CoV-2 virus is transmitted via salivary droplets.^{15,16} Furthermore, SARS-CoV-2 RNA has been detected in saliva for 37 days after onset.¹⁷

Spatter (mists) consists of droplets up to 50 μm in size that sink quickly, whereas aerosols are defined as droplet particles smaller than 5 μm that can remain airborne for extended periods. These small particles can reach deep into the bronchioles and have been reported to be significant in viral infections.¹⁸⁻²⁰ Therefore, these drops might contain infectious particles that pose a health threat to those within the spray's pattern.²¹⁻²⁴ It is reasoned, therefore, that aerosol generation from the use of a dental handpiece or an ultrasonic scaler in a patient's mouth has, at least in theory, the potential of transmitting the virus,^{7-11,25-30} even though to date no conclusive evidence of viral transmission occurring in a dental treatment environment has been documented.³¹ The half-life of SARS-CoV-2 in aerosols is reported to be approximately 1.1–1.2 h and larger droplets settled on surfaces as spatter have a median half-life of 5.6 h.³²

Therefore, this issue has raised a concern about the potential spread of the virus in the dental setting and has contributed to the need for the development of aerosol and spatter mitigation strategies.

In response to this challenge, new devices were introduced into the dental market. In a previous paper,³³ eight dry-field isolation methods were tested in a typodont setup in which air-water spray was generated with a high-speed handpiece without cutting teeth. Although standardized procedures were employed, the study was limited in that it did not reproduce real-life work scenarios. The current study aims to investigate the mitigation quality of 13 dry-field isolation methods in a simulated real-life setup that more closely replicates work scenarios encountered in dental practices.

This study attempts to compare the effectiveness of the following techniques:

1. High-volume evacuation—(HVE)
2. Rubber dam (RD) with HVE (RD and HVE)
3. Prototype 3D printed lip retractor with internal suction and funnel (PROTO) (Figure 1)
4. PROTO with additional HVE line (PROTO and HVE)
5. AeroSol away external vacuum device (AA)
6. AA with additional HVE line (AA and HVE)
7. IsoVac (ISO)
8. ISO with additional HVE line (ISO and HVE)
9. ReLeaf (ReLeaf)
10. ReLeaf with additional HVE line (ReLeaf and HVE)
11. Vac Station 8 cm away from mouth (VAC8)
12. VacStation 15 cm away from mouth (VAC15)
13. Vac Station 15 cm away from mouth plus HVE line (VAC15 and HVE)

2 | MATERIALS AND METHODS

Methods were adapted from Dahlke et al.³⁴ with one significant modification; in the current study, a crown preparation was performed on tooth number 30 and repeated five times for each device.

2.1 | Manikin

An oral anesthesia manikin head (model 1KOATM13, Columbia Denti-form Teaching Solutions, Inc., Lancaster, PA) with a metal skull, movable tongue, and flexible silicone face and mouth lining over an anatomically correct jaw with 28 permanent typodont teeth was selected to simulate the patient. The simulator was attached to a dental chair's headrest in the usual working position where the maxillary occlusal plane was perpendicular to the floor. Tooth #30 was selected for each test for crown preparation.

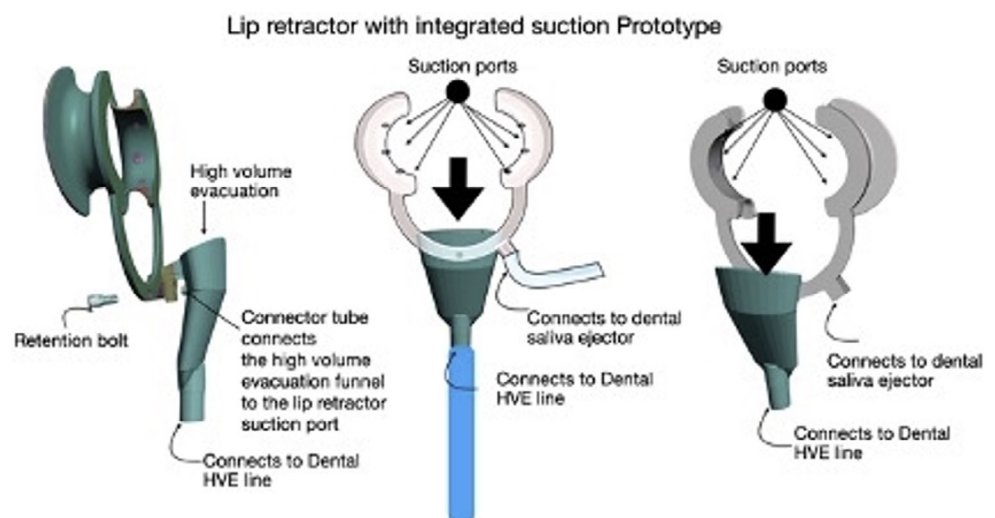


FIGURE 1 Diagram showing the 3D printed prototype retraction and funnel device (PROTO)

2.2 | Grid around manikin

A custom four by three-foot wooden board with black plastic coating was cut to fit around the manikin head and marked with a grid to score the spatter (Figure 2). The grid was created with fluorescent tape fixed tightly at 5 cm intervals to create areas of 5 cm². One clinician performed all crown preparations on tooth #30. Each preparation was completed in 2 min, with the operator sitting at the 8 o'clock position at a standard distance from the patient of 40 cm.

2.3 | Handpiece

A single high-speed handpiece (NSK Ti-Max X95L, Hoffman Estates, IL) was used and operated at the maximum torque and rotation speed of 200,000 revolutions per minute. The water flow through the handpiece was set at 25 ml/min, and the air pressure was selected to achieve an aerosol plume. The standard all-ceramic crown preparation was done using a diamond bur 878K016 (Brasseler USA, Savannah, GA) placed in the dental handpiece.

2.4 | Suction device setups

The dental chair (ADEC, Newberg, OR) setup used in this investigation is equipped with two separate HVE lines and one saliva ejector line. The following settings were used:

1. In this setup, and whenever a secondary HVE was used in our testing, a conventional disposable vented tip (Henry Schein, Melville,

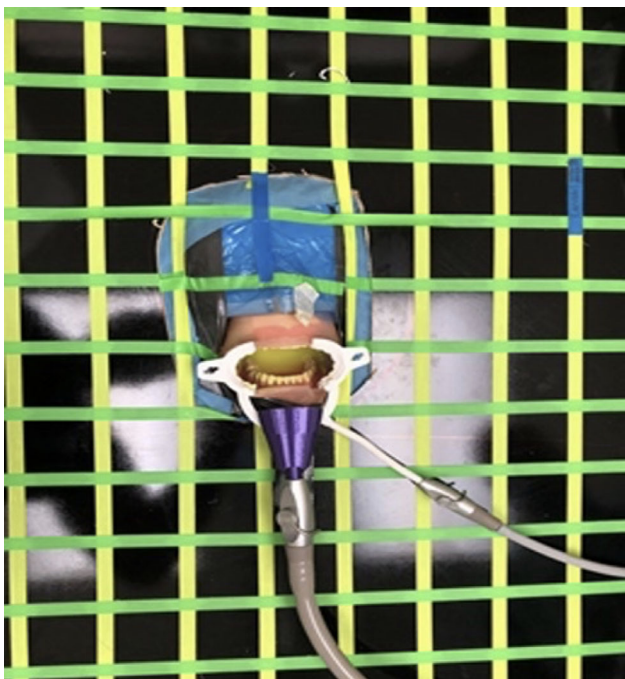


FIGURE 2 The spatter grid adapted around the manikin head. PROTO device is pictured in place in this image

- NY) was used in one of the HVE lines and positioned 4 cm from the tooth to be prepared.
2. A 3D printed internally irrigated retraction device (PROTO) was created with the Prusa MK3s 3D printer using Prusament PLA (Prusa Research, Prague, Czech Republic) with a layer height of 100 mm, extruder temperature of 220°C, and a bed temperature of 68°C with an infill of 100%. The frame included suction ports attached to the saliva ejector and the HVE line (Figures 1 and 2).
3. Conventional dental RD trials involved using a standard 6-in. non-latex dental dam (Flexi Dam, Coltène/Whaledent, Inc., Cuyahoga Falls, OH) punched with five holes to isolate teeth #27–31.
4. For the ISO (Zyris, Santa Barbara, CA) trials, a medium-size mouthpiece was used to obtain the best fit for the dental simulator head. The device was used alone and in conjunction with an HVE
5. The Aegis Aerosol VacStation (VAC) (CAO Group, Inc., West Jordan, UT) was tested at 8 (VAC8) and 15 (VAC15) cm from the manikin mouth. The VAC15 setup was tested alone and also in conjunction with a second HVE line, while the VAC8 was only tested by itself.
6. AA, AeroSol Away Auburn California, also was tested alone or in conjunction with HVE.
7. The Ivory[®] ReLeaf[™] (Kulzer North America, South Bend, IN) is a device designed to rest in the buccal vestibule and provide additional suction. Similar to the ISO device, yet without a mouth prop, it attaches to an HVE line. The ReLeaf device was tested alone and in conjunction with an additional HVE line.

2.5 | Measurements

1. Environmental Spatter: A 0.1% fluorescein dye solution (Sigma-Aldrich, St. Louis, MO) was added to the dental unit water supply for use during the simulated tooth preparation procedure.

The resulting spatter that escaped suction during the high-speed handpiece operation was visualized with a light-emitting diode dental curing light (Elipar[™] S10, 3 M, Inc., St. Paul, MN) emitting blue light with a spectral range of between 425 and 500 nm. The diode was held 8 cm from the paper's surface to fluoresce spatter droplets that had collected, and visualization was achieved using amber-colored protective glasses (Figure 3).

A calibrated operator reviewed the droplet field created during the trials. If even one spot of fluorescence was identified within a 5 cm² square, the cell was then scored as being contaminated. The number of squares with contamination were counted to determine the amount of spatter produced in each trial. Spatter generated using the high-speed handpiece with no suction served as the positive control value.

2. Face shield spatter: A grid was placed on a Face Shield (ZShield Health, ZVerse, Columbia, SC) worn by the operator during preparation of the typodont tooth in the manikin. The grid squares were 5 cm² in area and were created using the same fluorescent tape. If one spatter was detected in a grid cell, it was counted as positive (Figure 4).



FIGURE 3 Fluorescence Spatter after a test run. Grid is covered with new paper prior to each test run

3. Aerosol: Aerosol particles were measured using a real-time laser particle counter device (Casella Microdust Pro Aerosol Monitoring System, CEL712 Buffalo, NY) held 4 cm away from the orifice of the mouth. The atmospheric particulate matter with a diameter of less than $2.5 \mu\text{m}$ was recorded. Results were displayed in mg/m^3 units. The unit was calibrated before starting the experiments by running a 10-min calibration cycle in open fresh air.

Particle counts were read and recorded for 2 min during the crown preparation procedure. The use of the high-speed handpiece with no suction served as the positive control value. In contrast, negative control values were obtained by measuring the ambient air in the experimental room when no experiments were performed.

4. Sound: Soundmeter X by Faberacustical running on an iPhone X was used to measure decibels (dB) at a distance of 6 in. from the soft tissue glabella area of the mannequin head. During each experiment, a 30-s noise measurement was made for each tested device, with the noise level recorded over a wide range of frequencies between 20 and 20,000 Hz. Between 2 and 8 kHz, sounds are perceived as 10–20 dB louder than outside this range at the same intensity³⁵ and in this frequency range, we also find essential parts of speech information.³⁶ For the analysis, we are reporting the total sound level (TSL) as computed by the application. We do not report the sound for the setup HVE and RD



FIGURE 4 The face shield contained a grid pattern. In the simulated case illustrated, the sample run would score a three because three squares contain spatter

because we found it sufficient to report HVE alone. The same approach was implemented for the VAC setup, for which we only report sound measured when the VAC was placed 15 cm from the manikin mouth, that is, VAC15.

2.6 | Statistical analysis

Based on previous publications,³⁴ it was determined that five trials were necessary for each setup to achieve a power of 0.80 (effect size = 0.20; $p < 0.05$). For each outcome (Aerosol, Environmental, and Face Shield Spatter and Sound), generalized linear mixed models were used to look at differences between groups. A random intercept was included in the model to account for replicates. Normality assumptions were checked, and a log transformation was needed for all outcomes. Post-hoc pairwise comparisons were performed to compare least-squares means when appropriate using a Tukey adjustment. All statistical analyses were performed using SAS v9.4 (SAS Institute, Inc.). The graphs show the median values of the five trials performed for each group, and the bars show the 25th and 75th percentiles.

TABLE 1 Descriptive statistics

	Outcome	N	Mean	Std Dev	Median	25th Pctl	75th Pctl
Ambient Room	Spatter	0					
	Aerosol	5	0	0	0	0	0
	Face spatter	0					
	Total sound	5	61.09	0.88	60.85	60.65	61.41
Control	Spatter	5	54.8	6.06	54	49	60
	Aerosol	5	72.53	95.69	26.5	23.02	61
	Face spatter	5	4.4	3.21	6	2	7
HVE	Spatter	5	47.2	11.19	43	41	54
	Aerosol	5	3.55	3.55	2.03	0.78	5.85
	Face spatter	5	1.4	1.14	1	1	2
	Total sound	5	84.26	1.48	83.6	83.43	85.15
RD and HVE	Spatter	5	34	3.39	35	31	36
	Aerosol	5	1.54	0.71	1.37	0.98	1.87
	Face spatter	5	2.4	0.55	2	2	3
PROTO	Spatter	5	12.2	3.56	13	9	15
	Aerosol	5	0	0	0	0	0
	Face spatter	5	0.4	0.55	0	0	1
	Total sound	5	98.73	0.48	98.72	98.45	98.9
PROTO and HVE	Spatter	5	7.2	2.17	6	6	9
	Aerosol	5	0	0	0	0	0
	Face spatter	5	0.2	0.45	0	0	0
	Total sound	5	97	0.73	96.82	96.67	97.14
AA	Spatter	5	29	2.24	29	28	30
	Aerosol	5	8.28	7.42	6.1	3.4	8.53
	Face spatter	5	2.4	0.55	2	2	3
	Total sound	5	88.55	0.12	88.54	88.51	88.66
AA and HVE	Spatter	4	18	4.24	17.5	14.5	21.5
	Aerosol	5	0	0	0	0	0
	Face spatter	5	1	0.71	1	1	1
	Total sound	5	88.55	0.39	88.47	88.38	88.81
ISO	Spatter	5	32	1.58	32	31	33
	Aerosol	5	0.18	0.11	0.12	0.1	0.24
	Face spatter	5	2	0.71	2	2	2
	Total sound	5	86.73	0.8	86.66	86.19	86.95
ISO and HVE	Spatter	5	27.2	1.64	28	26	28
	Aerosol	5	0	0	0	0	0
	Face spatter	5	1.6	0.55	2	1	2
	Total sound	5	87.29	0.48	87.12	86.97	87.67
ReLeaf	Spatter	5	43	9.82	41	35	50
	Aerosol	5	12.74	18.48	7.21	1.33	9.47
	Face spatter	5	3.4	2.07	3	2	3
	Total sound	5	86.69	1.2	87.19	86.91	87.34
ReLeaf and HVE	Spatter	5	28.6	3.13	28	27	28
	Aerosol	5	0	0	0	0	0
	Face spatter	5	1.2	1.3	1	0	2
	Total sound	5	86.57	0.37	86.55	86.34	86.64

TABLE 1 (Continued)

	Outcome	N	Mean	Std Dev	Median	25th Pctl	75th Pctl
VAC8	Spatter	5	11.4	2.3	11	10	12
	Aerosol	5	0.29	0.4	0.12	0.03	0.31
	Face Spatter	5	0	0	0	0	0
	Total sound	5	79.67	0.77	79.41	79.31	80.07
VAC15	Spatter	5	31.4	4.39	30	29	31
	Aerosol	5	7.43	2.5	8.84	7.24	8.9
	Face spatter	5	1.4	0.55	1	1	2
	Total sound	5	76.98	0.51	76.9	76.87	77.42
VAC15 and HVE	Spatter	5	30.8	1.64	31	31	32
	Aerosol	5	0	0	0	0	0
	Face spatter	5	1.8	0.84	2	1	2
	Total sound	5	86.93	0.38	87.07	86.58	87.14

Note: Legend: Measurement units: 1. Spatter—number of contaminated squares in the experimental grid. 2. Aerosols-mg/m³. RD with HVE (RD and HVE), PROTO with additional HVE line (PROTO and HVE), AA with additional HVE line (AA and HVE), ISO with additional HVE line (ISO and HVE), ReLeaf with additional HVE line (ReLeaf and HVE), Vac Station 8 cm away from mouth (VAC8), VacStation 15 cm away from mouth (VAC15), Vac Station 15 cm away from mouth plus HVE line (VAC15 and HVE).

Abbreviations: HVE, high-volume evacuation; RD, rubber dam; PROTO, Prototype 3D printed lip retractor with internal suction and funnel; AA, Aerosol Away external vacuum device; Iso, IsoVac; ReLeaf, ReLeaf.

3 | RESULTS

Descriptive statistics of the results can be found in Table 1. The ambient room results obtained before operating the high speed are considered negative control values. In contrast, the positive control results labeled as “Control” were obtained when the high speed was used to prepare the tooth without any suction mitigation devices.

3.1 | Environmental spatter

The environmental spatter analysis (Table 2 and Figure 5) shows that a single HVE line performs similar to the ISO and ReLeaf devices. Although adding the RD to the HVE does not show a statistical improvement compared to HVE alone, the spatter results are improved, showing that the RD + HVE setup is statistically similar to the AA external vacuum device, ISO with or without HVE, ReLeaf with or without HVE, and VacStation 15 cm away from mouth (VAC15) with or without HVE. Only the prototype (PROTO) alone or with HVE and the VacStation 8 cm away from mouth (VAC8) performed better than the setup RD + HVE.

PROTO alone performed better than most setups except for AA + HVE and VAC8. PROTO, together with an additional HVE line, performs better than all other settings that were tested.

ISO or ReLeaf use provided inferior spatter mitigation compared to when an additional HVE line was added to the mix. Both devices had similar performance. Finally, VAC8 performed similarly to PROTO and significantly better than all other settings, with the exception of PROTO + HVE. Interestingly, once the VAC is distanced to 15 cm from the mouth, the spatter mitigation performance deteriorates

significantly, and even adding an additional HVE line does not improve the spatter results.

3.2 | Face shield spatter

The primary observation (Table 3 and Figure 6) is that HVE alone performed similarly to all other mitigation methods and was not statistically different from the control. When RD was added to the HVE setup, it decreased the HVE efficiency compared to PROTO and VAC8, probably because the RD causes spatter to bounce. Although PROTO with or without HVE and VAC8 had statistically better results than the control, overall, all mitigation devices had median Face Shield Spatter absolute results ranging between 0 and 3. When HVE was added to ISO, it was statistically inferior only to VAC8, whereas ReLeaf + HVE performed similarly to both the control and all other mitigation methods.

3.3 | Aerosol

It is worth noticing (Table 4 and Figure 7) that the setting RD + HVE performed similarly to all other mitigation techniques. HVE alone was inferior to ambient negative control values and to PROTO. However, when HVE was used in conjunction with any other device tested, it brought the aerosols to negative control levels (ambient room) values. PROTO alone was able to mitigate aerosol to negative control (ambient) values. When used alone, AA, ReLeaf, and VAC15 were significantly inferior to all other aerosol mitigation setups.

TABLE 2 Environmental spatter

	Control	HVE	RD and HVE	PROTO	PROTO and HVE	AA	AA and HVE	ISO	ISO and HVE	Releaf	Releaf and HVE	VAC8	VAC15	VAC15 and HVE
Control		0.9655	0.0059*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	0.0011*	<0.0001*	0.5628	<0.0001*	<0.0001*	0.0005*	0.0003*
HVE	0.9655		0.2745	<0.0001*	<0.0001*	0.0076*	<0.0001*	0.0907	0.0012*	0.9999	0.0049*	<0.0001*	0.0515	0.0375*
RD and HVE	0.0059*	0.2745		<0.0001*	<0.0001*	0.9778	<0.0001*	1	0.7823	0.7943	0.9528	<0.0001*	1	0.9998
PROTO	<0.0001*	<0.0001*	<0.0001*		0.0014*	<0.0001*	0.0661	<0.0001*	<0.0001*	<0.0001*	<0.0001*	1	<0.0001*	<0.0001*
PROTO and HVE	<0.0001*	<0.0001*	<0.0001*	0.0014*		<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	0.0054*	<0.0001*	<0.0001*
AA	<0.0001*	0.0076*	0.9778	<0.0001*	<0.0001*		0.0077*	0.9997	1	0.0762	1	<0.0001*	1	1
AA and HVE	<0.0001*	<0.0001*	<0.0001*	0.0661	<0.0001*	0.0077*		0.0005*	0.0363*	<0.0001*	0.0116*	0.0231*	0.001*	0.0015*
ISO	0.0011*	0.0907	1	<0.0001*	<0.0001*	0.9997	0.0005*		0.9706	0.4563	0.9987	<0.0001*	1	1
ISO and HVE	<0.0001*	0.0012*	0.7823	<0.0001*	<0.0001*	1	0.0363*	0.9706		0.0164*	1	<0.0001*	0.993	0.9973
Releaf	0.5628	0.9999	0.7943	<0.0001*	<0.0001*	0.0762	<0.0001*	0.4563	0.0164*		0.0529	<0.0001*	0.3185	0.2562
Releaf and HVE	<0.0001*	0.0049*	0.9528	<0.0001*	<0.0001*	1	0.0116*	0.9987	1	0.0529		<0.0001*	0.9999	1
VAC8	<0.0001*	<0.0001*	<0.0001*	1	0.0054*	<0.0001*	0.0231*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*
VAC15	0.0005*	0.0515	1	<0.0001*	<0.0001*	1	0.001*	1	0.993	0.3185	0.9999	<0.0001*		1
VAC15 and HVE	0.0003*	0.0375*	0.9998	<0.0001*	<0.0001*	1	0.0015*	1	0.9973	0.2562	1	<0.0001*	1	

Note: RD with HVE (RD and HVE), PROTO with additional HVE line (PROTO and HVE), AA with additional HVE line (AA and HVE), ISO with additional HVE line (ISO and HVE), Releaf with additional HVE line (Releaf and HVE), Vac Station 8 cm away from mouth (VAC8), VacStation 15 cm away from mouth (VAC15), Vac Station 15 cm away from mouth plus HVE line (VAC15 and HVE). *Denotes statistically significant difference.

Abbreviations: HVE, high-volume evacuation; RD, rubber dam; PROTO, Prototype 3D printed lip retractor with internal suction and funnel; AA, Aerosol Away external vacuum device; IsoVac; Releaf, Releaf.

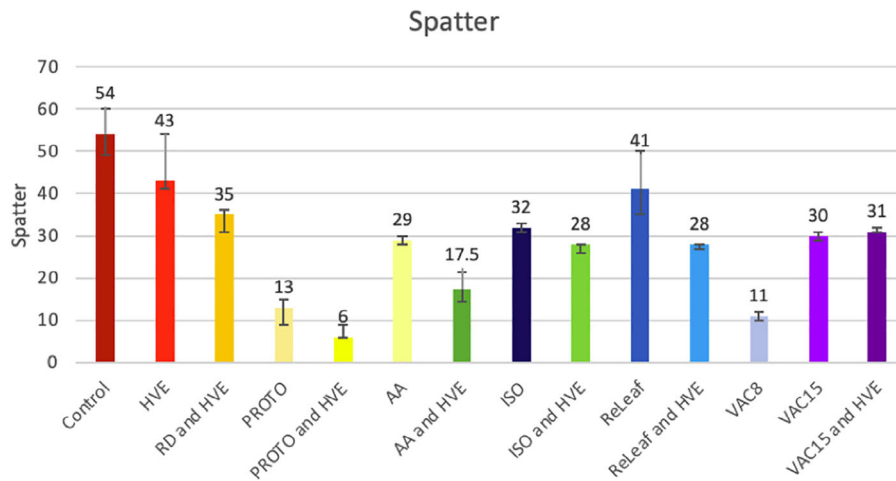


FIGURE 5 Environmental spatter. Legend: Measurement units: Spatter—number of contaminated squares in the experimental grid. Numbers above columns denote median values and the bars denote the 25th and 75th percentiles. Abbreviations: high-volume evacuation—(HVE), rubber dam (RD) with HVE (RD and HVE), Prototype 3D printed lip retractor with internal suction and funnel (PROTO), PROTO with additional HVE line (PROTO and HVE), Aerosol away external Vacuum device (AA), Aerosol away with additional HVE line (AA and HVE), IsoVac (ISO), ISO with additional HVE line (ISO and HVE), ReLeaf (ReLeaf), ReLeaf with additional HVE line (ReLeaf and HVE), Vac Station 8 cm away from mouth (VAC8), VacStation 15 cm away from mouth (VAC15), Vac Station 15 cm away from mouth plus HVE line (VAC15 and HVE)

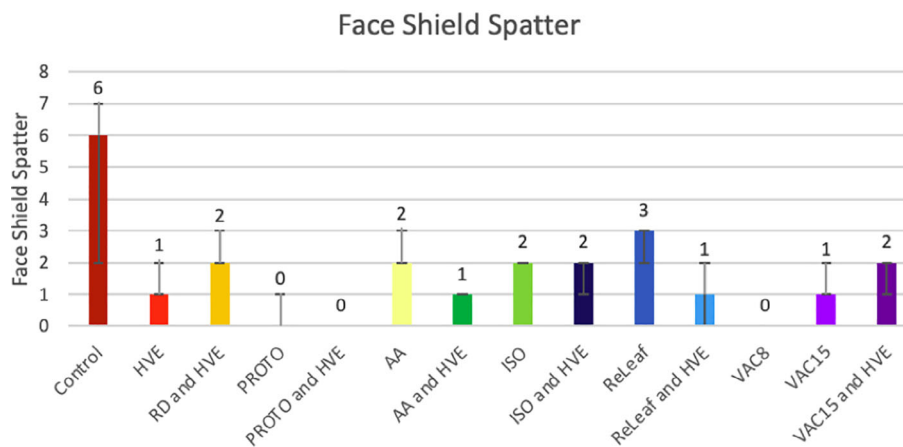


FIGURE 6 Face shield spatter. Legend: Measurement units: Spatter—number of contaminated squares on the experimental grid. Numbers above columns denote median values and the bars denote the 25th and 75th percentiles. Abbreviations: high-volume evacuation—(HVE), rubber dam (RD) with HVE (RD and HVE), Prototype 3D printed lip retractor with internal suction and funnel (PROTO), PROTO with additional HVE line (PROTO and HVE), Aerosol away external Vacuum device (AA), Aerosol away with additional HVE line (AA and HVE), IsoVac (ISO), ISO with additional HVE line (ISO and HVE), ReLeaf (ReLeaf), ReLeaf with additional HVE line (ReLeaf and HVE), Vac Station 8 cm away from mouth (VAC8), VacStation 15 cm away from mouth (VAC15), Vac Station 15 cm away from mouth plus HVE line (VAC15 and HVE)

3.4 | Total sound level

Although the VAC had the lowest noise level (less than 80 dB), it loses this advantage when an HVE line is added to the mix (Table 5 and Figure 8). Next is a single HVE line with a median TSL of 83.6 dB. Most setups (AA, AA+HVE, ISO, ISO + HVE, ReLeaf, ReLeaf+HVE, VAC15 + HVE) have TSL levels between 86.55 and 88.54 dB; although the statistical analysis shows some statistical differences among these setups, it is probable that the range of less than 2 dB is not practically very significant. The setup PROTO with or without HVE has significantly higher TSL at 96.82 and 98.72 dB, respectively.

4 | DISCUSSION

The American Dental Association,³⁷ emphasized the importance of oral health care and that millions of patients have been safely treated during the last few months of the pandemic. They emphasize that appropriate personal protective equipment in concert with aerosol-generating procedure (AGP) mitigation efforts are responsible for this success. This study brings to light the most successful techniques that can be incorporated into the dental practice to mitigate spatter and aerosols from AGP.

TABLE 3 Face shield spatter

	Control	HVE	RD and HVE	PROTO and HVE	AA	AA and HVE	ISO	ISO and HVE	ReLeaf	ReLeaf and HVE	VAC8	VAC15	VAC15 and HVE
Control		0.3786	0.9998	0.0026*	0.9998	0.1321	0.9763	0.7908	1	0.1321	<0.0001*	0.5879	0.8974
HVE	0.3786		0.9078	0.8065	0.9078	1	0.9958	1	0.455	1	0.1719	1	0.9998
RD and HVE	0.9998	0.9078		0.0367*	1	0.6074	1	0.9981	1	0.6074	0.0013*	0.9799	0.9998
PROTO	0.0026*	0.8065	0.0367*		0.0367*	0.9799	0.1407	0.396	0.0038*	0.9799	0.9981	0.6074	0.2692
PROTO and HVE	0.0004*	0.455	0.0076*	1	0.0076*	0.8065	0.0367*	0.1407	0.0006*	0.8065	1	0.2692	0.0832
AA	0.9998	0.9078	1	0.0367*	0.6074	1	0.9981	1	0.6074	0.0013*	0.0013*	0.9799	0.9998
AA and HVE	0.1321	1	0.6074	0.9799	0.6074	0.9078	0.9958	0.1719	1	0.455	0.455	0.9998	0.9799
ISO	0.9763	0.9958	1	0.1407	0.0367*	1	0.9078	1	0.9888	0.9078	0.0076*	0.9998	1
ISO and HVE	0.7908	1	0.9981	0.396	0.1407	0.9981	1	0.8531	0.9958	0.0367*	1	1	1
ReLeaf	1	0.455	1	0.0038*	0.0006*	1	0.9888	0.8531	0.1719	0.1719	<0.0001*	0.6694	0.9368
ReLeaf and HVE	0.1321	1	0.6074	0.9799	0.6074	1	0.9078	0.9958	0.1719	0.455	0.455	0.9998	0.9799
VAC8	<0.0001*	0.1719	0.0013*	0.9981	1	0.0013*	0.0076*	0.0367	<0.0001*	0.455	0.0832	0.0196*	0.0196*
VAC15	0.5879	1	0.9799	0.6074	0.2692	0.9799	0.9998	1	0.6694	0.9998	0.0832	1	1
VAC15 and HVE	0.8974	0.9998	0.9998	0.2692	0.0832	0.9998	0.9799	1	0.9368	0.9799	0.0196	1	1

Note: RD with HVE (RD and HVE), PROTO with additional HVE line (PROTO and HVE), AA with additional HVE line (AA and HVE), ISO with additional HVE line (ISO and HVE), ReLeaf with additional HVE line (ReLeaf and HVE), Vac Station 8 cm away from mouth (VAC8), VacStation 15 cm away from mouth (VAC15), Vac Station 15 cm away from mouth plus HVE line (VAC15 and HVE). *Denotes statistically significant difference.

Abbreviations: HVE, high-volume evacuation; RD, rubber dam; PROTO, Prototype 3D printed lip retractor with internal suction and funnel; AA, Aerosol Away external vacuum device; Iso, IsoVac; ReLeaf, ReLeaf.

TABLE 4 Aerosol creation

Ambient Room	Control	HVE	RD and HVE	PROTO	PROTO and HVE	AA	AA and HVE	ISO	ISO and HVE	ReLeaf	ReLeaf and HVE	VAC8	VAC15	VAC15 and HVE
Ambient Room	<0.0001*	0.0435*	0.4029	1	1	<0.0001*	1	1	1	<0.0001*	1	1	<0.0001*	1
Control	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	0.0006*	<0.0001*	<0.0001*	<0.0001*	0.0002*	<0.0001*	<0.0001*	0.0013*	<0.0001*
HVE	0.0435*	<0.0001*	0.9994	0.0435*	0.0435*	0.69	0.0435*	0.1373	0.0435*	0.8411	0.0435*	0.2075	0.538	0.0435*
RD and HVE	<0.0001*	0.9994	0.4029	0.4029	0.4029	0.1263	0.4029	0.7138	0.4029	0.2206	0.4029	0.8259	0.0738	0.4029
PROTO	1	0.0435*	0.4029	1	1	<0.0001*	1	1	1	<0.0001*	1	1	<0.0001*	1
PROTO and HVE	1	0.0435*	0.4029	1	1	<0.0001*	1	1	1	<0.0001*	1	1	<0.0001*	1
AA	<0.0001*	0.0006*	0.69	<0.0001*	<0.0001*	<0.0001*	<0.0001*	0.0002*	<0.0001*	1	<0.0001*	0.0003*	1	<0.0001*
AA and HVE	1	0.0435*	0.4029	1	1	<0.0001*	1	1	1	<0.0001*	1	1	<0.0001*	1
ISO	1	<0.0001*	0.7138	1	1	0.0002	1	1	1	0.0004	1	1	<0.0001*	1
ISO and HVE	1	<0.0001*	0.4029	1	1	<0.0001*	1	1	1	<0.0001*	1	1	<0.0001*	1
ReLeaf	<0.0001*	0.0002*	0.2206	<0.0001*	<0.0001*	1	<0.0001*	0.0004*	<0.0001*	<0.0001*	<0.0001*	0.0008*	1	<0.0001*
ReLeaf and HVE	1	0.0435*	0.4029	1	1	<0.0001*	1	1	1	<0.0001*	1	1	<0.0001*	1
VAC8	1	<0.0001*	0.8259	1	1	0.0003*	1	1	1	0.0008*	1	1	0.0002*	1
VAC15	<0.0001*	0.0013*	0.0738	<0.0001*	<0.0001*	1	<0.0001*	<0.0001*	<0.0001*	1	<0.0001*	0.0002*	<0.0001*	<0.0001*
VAC15 and HVE	1	<0.0001*	0.0435*	1	1	<0.0001*	1	1	1	<0.0001*	1	1	<0.0001*	1

Note: RD with HVE (RD and HVE), PROTO with additional HVE line (PROTO and HVE), AA with additional HVE line (AA and HVE), ISO with additional HVE line (ISO and HVE), ReLeaf with additional HVE line (ReLeaf and HVE), Vac Station 8 cm away from mouth (VAC8), Vac Station 15 cm away from mouth (VAC15), Vac Station 15 cm away from mouth plus HVE line (VAC15 and HVE). *Denotes statistically significant difference.

Abbreviations: HVE, high-volume evacuation; RD, rubber dam; PROTO, Prototype 3D printed lip retractor with internal suction and funnel; AA, Aerosol Away external vacuum device; Iso, IsoVac; ReLeaf, ReLeaf.

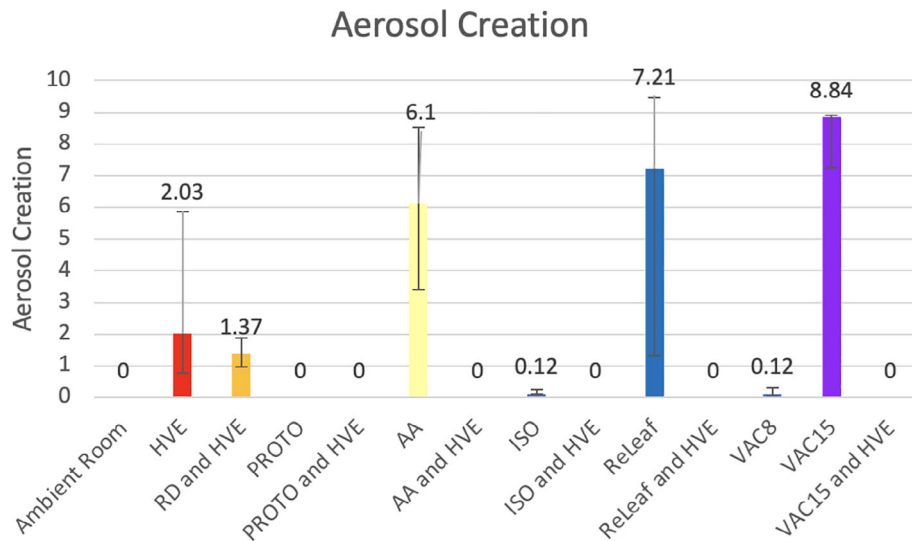


FIGURE 7 Aerosol creation. Legend: Measurement units: Aerosols-mg/m³. Numbers above columns denote median values and the bars denote the 25th and 75th percentiles. Abbreviations: high-volume evacuation—(HVE), rubber dam (RD) with HVE (RD and HVE), Prototype 3D printed lip retractor with internal suction and funnel (PROTO), PROTO with additional HVE line (PROTO and HVE), Aerosol away external vacuum device (AA), Aerosol away with additional HVE line (AA and HVE), IsoVac (ISO), ISO with additional high-volume evacuation (HVE) line (ISO and HVE), ReLeaf (ReLeaf), ReLeaf with additional HVE line (ReLeaf and HVE), Vac Station 8 cm away from mouth (VAC8), VacStation 15 cm away from mouth (VAC15), Vac Station 15 cm away from mouth plus HVE line (VAC15 and HVE)

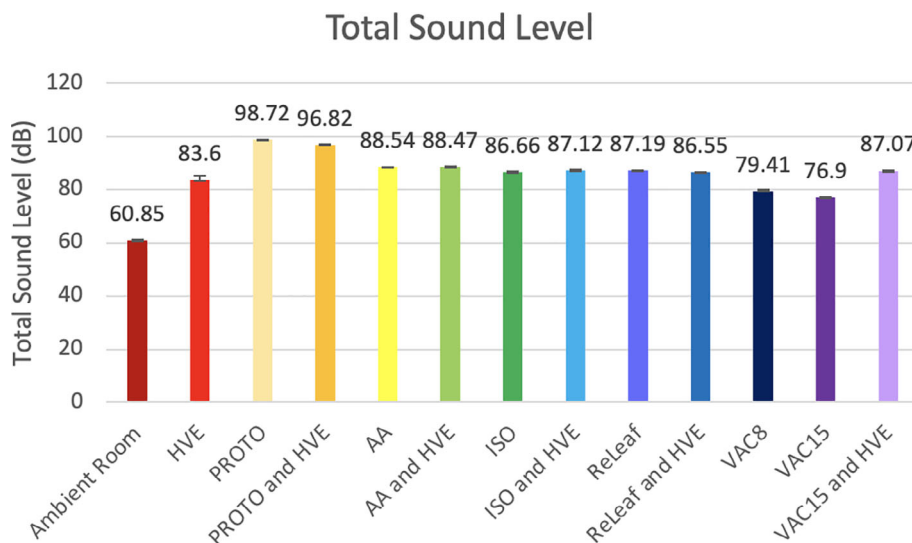


FIGURE 8 Total sound level. Legend: Measurement units: Sound-dB. Numbers above columns denote median values and the bars denote the 25th and 75th percentiles. Abbreviations: high-volume evacuation—(HVE), rubber dam (RD) with HVE (RD and HVE), Prototype 3D printed lip retractor with internal suction and funnel (PROTO), PROTO with additional HVE line (PROTO and HVE), Aerosol away external vacuum device (AA), Aerosol away with additional HVE line (AA and HVE), IsoVac (ISO), ISO with additional HVE line (ISO and HVE), ReLeaf (ReLeaf), ReLeaf with additional HVE line (ReLeaf and HVE), Vac Station 8 cm away from mouth (VAC8), VacStation 15 cm away from mouth (VAC15), Vac Station 15 cm away from mouth plus HVE line (VAC15 and HVE)

The creation of aerosol and spatter during dental procedures has been a keen focus of concern during the COVID-19 pandemic. Many different mitigation strategies and devices have been created and advertised to address these concerns. However, there has not been, any clear understanding if these devices are effective. Ravenel et al.³³ demonstrated that several of the conventional evacuation

apparatuses found in the dental practice could effectively reduce and eliminate aerosol and spatter when used in combination, typically with both and intra and extraoral high volume evacuation. However, it did not replicate aerosol and spatter creation that occurs when actually working with a handpiece intraorally since the preparation of teeth was not part of that study. This paper attempts to demonstrate

TABLE 5 Total sound level

Ambient Room	HVE	PROTO	PROTO and HVE	AA	AA and HVE	ISO	ISO and HVE	ReLeaf	ReLeaf and HVE	VAC8	VAC15	VAC15 and HVE
Ambient Room	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*
HVE	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	0.0005*	<0.0001*	0.0007*	0.0014*	<0.0001*	<0.0001*	0.0001*
PROTO	<0.0001*	0.1433	0.1433	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*
PROTO and HVE	<0.0001*	0.1433	0.1433	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*
AA	<0.0001*	<0.0001*	<0.0001*	1	0.0378*	0.4166	0.4166	0.0299*	0.0156*	<0.0001*	<0.0001*	0.102
AA and HVE	<0.0001*	<0.0001*	<0.0001*	1	0.0383*	0.4199	0.4199	0.0303*	0.0158*	<0.0001*	<0.0001*	0.1032
ISO	0.0005*	<0.0001*	<0.0001*	0.0378*	0.0383*	0.9956	0.9956	1	1	<0.0001*	<0.0001*	1
ISO and HVE	<0.0001*	<0.0001*	<0.0001*	0.4166	0.4199	0.9956	0.9956	0.9915	0.9652	<0.0001*	<0.0001*	0.9999
ReLeaf	0.0007*	<0.0001*	<0.0001*	0.0299*	0.0303*	1	0.9915	1	1	<0.0001*	<0.0001*	1
ReLeaf and HVE	0.0014*	<0.0001*	<0.0001*	0.0156*	0.0158*	1	0.9652	1	1	<0.0001*	<0.0001*	0.9999
VAC8	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*
VAC15	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*
VAC15 and HVE	0.0001*	<0.0001*	<0.0001*	0.102	0.1032	1	0.9999	1	0.9999	<0.0001*	<0.0001*	<0.0001*

Note: RD with HVE (RD and HVE), PROTO with additional HVE line (PROTO and HVE), AA with additional HVE line (AA and HVE), ISO with additional HVE line (ISO and HVE), ReLeaf with additional HVE line (ReLeaf and HVE), Vac Station 8 cm away from mouth (VAC8), VacStation 15 cm away from mouth (VAC15), Vac Station 15 cm away from mouth plus HVE line (VAC15 and HVE). *Denotes statistically significant difference.

Abbreviations: HVE, high-volume evacuation; RD, rubber dam; PROTO, Prototype 3D printed lip retractor with internal suction and funnel; AA, Aerosol Away external vacuum device; Iso, IsoVac; ReLeaf, ReLeaf.

potential effective mitigation strategies that can be employed while the dentist actually works in the oral cavity.

Environmental spatter on the patient, the test site area, and the operator face shield was measured during this study. All tested devices and configurations tested showed some spatter formation on the test area, although the results show that some setups performed better. To that end, we observed that the PROTO and VAC8 setups performed better than other setups, without the need to add a second HVE line to mitigate spatter. The same trend was observed for the Face Shield spatter, where these two devices had a median value of zero. However, some spatter was found on the operator face shield with the VAC at 15 cm, either with or without secondary HVE. The suction limitations of the VAC over a larger distances from the operating area may have contributed to this higher face shield spatter.

The PROTO device that uses both the HVE line and the saliva ejector line was able to mitigate aerosols to a satisfactory level. This also was observed for ISO and VAC8. The dome-like clear shield of the VAC enables the clinician to view the operating area; however, the close proximity to the oral cavity for effective use may hinder effective clinician performance. At 15 cm (approximately 6 in.), the VAC aerosol mitigation ability dropped significantly. However, in contrast with the Face Shield spatter, when this greater distance was used in conjunction with a secondary HVE, the aerosol was entirely contained. The ReLeaf and AA devices used alone were less effective in aerosol mitigation in our testing. For both these devices, good aerosol mitigation was obtained by incorporating a secondary HVE placed correctly in the treated area. All other setups also resulted in considerable aerosol mitigation when a second line of HVE was added to the mix.

Regarding RD use with HVE, our results show that it is an efficient aerosol mitigation strategy. These results are consistent with previously reported data.³³ This is surprising because our study showed that HVE alone provided only partial aerosol mitigation. We can postulate that the use of RD limits the dispersion of aerosols in the patient's mouth and the resulting turbulence that may cause the aerosols to escape from the HVE suction.

Sound also comes into play when attempting to mitigate aerosol and spatter in the dental workplace. As previously discussed in Ravenel et al.³³ the sound output of these various mitigation devices can be problematic, especially in light of the Occupational Safety and Health Administration (OSHA)³⁸ and National Institute for Occupational Safety and Health (NIOSH) maximum noise standards³⁹ of 90 and 85 dB respectively. In this study, the TSL of the setups tested ranged from a low of 76.9 dB for VAC 15 to a high of 98.72 dB for PROTO. Most setups TSL measured between the OSHA and the NIOSH standards, that is, between 85 and 90 dB. One reason the PROTO device might be loud is that it was a 3D printed prototype with an irregular surface.

5 | CONCLUSION

Within the limitations of this study, it can be concluded that the dental community has at its disposal equipment and instrumentation that

can significantly mitigate the creation of aerosol when performing AGPs. The simplest and most widely used solution setup HVE + RD (HVE with RD) allows satisfactory mitigation of spatter and most aerosols when the clinical situation allows. However, this study demonstrates that there are other mitigation strategies that are more effective, particularly when used in conjunction with a secondary HVE apparatus. These simple setups can be quickly incorporated into every practice, often without requiring a significant capital investment.

DISCLOSURE

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